HEAT TRANSMISSION IN A VACUUM EVAPORATOR

BY

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ARMOUR INSTITUTE OF TECHNOLOGY

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The efficiency of heat
transmission in a vacuum

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THE EFFICIENCY OF HEAT TRANSMISSION IN A VACUUM EVAPORATOR.

A THESIS

PRESENTED BY

CURT W. DIEMECKE

AND

I. YAMAMOTO

TO THE

PRESIDENT AND FACULTY

OF

ARMOUR INSTITUTE OF TECHNOLOGY

FOR THE DEGREE OF

BACHELOR OF SCIENCE

IN

CHEMICAL ENGINEERING

HAVING COMPLETED THE PRESCRIBED COURSE OF STUDIES

IN

CHEMICAL ENGINEERING.

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Part I.

Introduction.

There was formerly in the "Industrial Chemistry" laboratory a rectangular, horizontal tube evaporator, installed by the Swenson Evaporator Company for experimental purposes. Its efficiency had been tested from time to time by different students in the chemical engineering department, and it had proved to be a very satisfactory machine. A new type of evaporator, called the "Swenson-Kermer" evaporator, was installed this year by the same company in place of the old one, but instead of the single tube in the old type, it has a series of double tubes, one inside the other. The steam passing through between the tubes, heats the liquid about the outer tube and that in the inner tube.

We made a series of tests on the new type and our results show that it is a very efficient evaporator; indeed, its efficiency, according to our tests, was, on the average, six per cent higher than that of the older type, as determined by other workers.

Part 2.

Description of Apparatus and Tests.

The Evaporator.

The general outline and dimensions of the evaporator are shown in detail in the accompanying drawing, and a sectional view is shown in the other drawing furnished by the Swenson Evaporator Company.

The walls of the evaporator are half-inch cast iron plates, bolted with three-eighths inch bolts. The inner and outer tubes are, respectively, standard three quarters inch and one and one quarter inch copper tubes. The inner tubes are two and seven-tenths feet long, and the outer tubes one and ninety six hundredths feet. There are forty eight sets of inner and outer tubes, arranged six in a horizontal line and eight in a perpendicular line, the distance between the pipes being two inches from center to center. The inner tubes are arranged in groups of four each, the two lower ones being connected to the two upper tubes of the group immediately below through a socket attached to the outside walls of the steam chambers. The outer tubes are fitted into holes in the outside

walls of the steam chambers, are open at each end, and have no group arrangements.

In the re ar of the evaporator is a liquid inlet chamber, from which the liquid passes through the inner tubes and through one of the inter-connecting pipes projecting outside of the evaporator. Valve connections are so made that the liquid may be made to circulate through the inner tubes from the bottom of the evaporator to the top, or vice versa; or, if necessary, the liquid may be made to pass directly into the evaporator without passing through the inner tubes at all. In the latter case, the evaporator acts as the ordinary single tube evaporator.

A baffle plate is bolted in proper position in the dome of the evaporator in order to prevent entrainment of liquid going with the vapors. Another perforated baffle plate is placed in the mid-portion of the evaporator in order to hinder a sudden rush of foaming liquids.

The vapors are taken from the evaporator through a four inch cast iron pipe which leads

them to a jet condenser of the parallel current, standard low vacuum type.

The water from the condenser is exhausted by a direct acting steam pump. The steam is exhausted into a trap, (Crane Company's No. I), in which a complete condensation takes place.

The Auxiliaries.

The Auxiliaries.

The Pump:

The pump was manufactured by the American Pump Company under the following specifications:

Diameter of steam cylinder,	4 inches.
Diameter of water cylinder,	5 inches.
Diameter of piston rod,	7/8 inch.
Length of stroke,	6 inches.

The Gauges:

The steam pressure gauge was made by the Ashcroft Manufacturing Company. It was calibrated with an oil tester, and from the data obtained, a calibration curve was plotted. From this curve, the correct readings were read off. The vacuum gauge was made by the Belfield Company. It was calibrated against a mercury column, and the needle was adjusted to give correct readings.

The Scale:

A platform scale made by the Howe Company was used to weigh the condensed steam

and the water to be evaporated.

The Calorimeter:

A Carpenter separating calorimeter was used. The entrained water was read directly from the glass tube gauge, and the condensed steam was weighed.

The Thermometers:

The thermometers were of the Fahrenheit scale, and had all been previously calibrated.

Methods Employed in this Test.

Methods Employed in this Test.

The duration of the runs was an hour, except for Runs 4, 5, and 6, each of which was only one-half hour. The liquid evaporated during all the runs was tap water.

After examining the evaporator for any leaks or imperfections, and when everything was in order, the vacuum pump was started and the condensing water turned on. The water, whose weight and temperature was known, was introduced into the evaporator up to a certain point slightly above the upper level of the top tubes. The run was made under as nearly constant conditions as possible, and all readings were taken at five minute intervals. Throughout the whole experiment, the pressure was regulated to obtain five pounds gauge pressure, but the vacuum was varied from sixteen to twenty inches of mercury. Except in Runs 5 and 6, water was added at frequent intervals, so as to keep the

water level as nearly constant as consistently possible. In Runs 5 and 6, a known quantity of water was introduced into the evaporator and was boiled down to see if it would affect the efficiency of the evaporator. The exhaust steam was collected and weighed at convenient intervals. At the end of the run, the steam was shut off simultaneously with the breaking of the vacuum. The liquid was then withdrawn and weighed.

The temperature of the steam was taken at entrance to the steam chamber rather than in the steam chamber itself, because the primary object of the experiment was to determine the efficiency of the evaporator as a whole rather than the heat transmission of the tubes, although the difference arising from this source was so small as to be practically negligible. The pressure gauge was connected to the steam chamber, and the latent heat of vaporization of the steam at the corresponding pressure was found in the steam tables in Kent's "Pocket Book for Mechanical Engineers". The exhaust

steam temperature was read on a thermometer placed in the exhaust line. The quality of the entering steam was determined by means of a Carpenter separating calorimeter, connected into the steam line near the entrance into the steam chamber. A number of tests showed that the quality of the steam was fairly constant at about 95 per cent. We therefore took this value for the whole experiment.

Data on Tubes.

Tubes.

Material,	Copper.
Diameter of inner tubes,	0.75 inch.
Length of inner tubes,	2.7 feet.
Number of inner tubes,	48
Heating surface of inner tubes,	20 sq. ft.
Diameter of outer tubes,	1.25 inch.
Length of outer tubes,	1.96 feet.
Heating surface of outer tubes,	32 sq. ft.
Number of outer tubes,	48
Total heating surface,	52 sq. ft.

Part 3.

Results of Tests.

Gauge Calibration and Correction.

MECHANICAL ENGINEERING LABORATORY

ARMOUR INSTITUTE OF TECHNOLOGY

Date Thurs., Apr. 8, 1915.

CALIBRATION OF VACUUM GAUGE.

By comparison with mercury column.

Maker and number of gauge Belfield Company, Phildelphia, Penn.

Observer I. Yamamoto, C. Diemecke.

Number	MERCURY COLUMN				GAUGE READING		Error
	INCHES			Pounds	Inches Mercury	Pounds	
	Up	Down	Mean				
		Before adjustment.					
		18.5			17.4		
		17.0			15.6		
		15.1			13.9		
		13.0			11.6		
		11.0			9.6		
		9.1			7.8		
		6.9			5.2		
		2.8			1.4		

MECHANICAL ENGINEERING LABORATORY

ARMOUR INSTITUTE OF TECHNOLOGY

Date Thurs., Apr. 8, 1915.

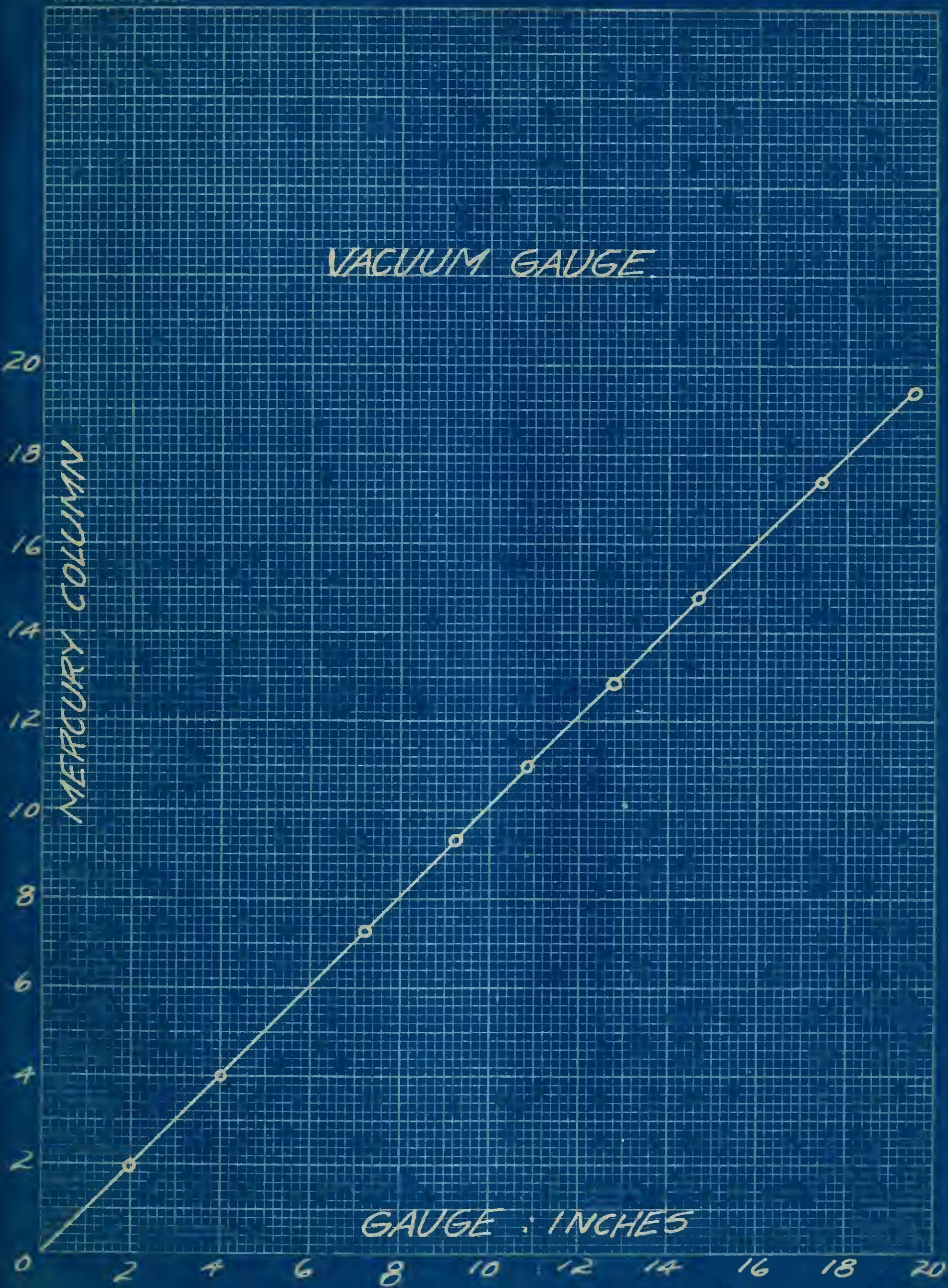
CALIBRATION OF VACUUM GAUGE.

By comparison with mercury column.

Maker and number of gauge Belfield, Company, Philadelphia, Penn.

Observer I. Yamamoto, C. Diemecke.

Number	MERCURY COLUMN				GAUGE READING		Error
	INCHES			Pounds	Inches Mercury	Pounds	
	Up	Down	Mean				
		After adjustment.					
		19.5			19.4		
		17.4			17.4		
		14.8			14.6		
		12.8			12.8		
		11.0			10.8		
		9.3			9.2		
		7.25			7.2		
		4.0			4.0		
		2.0			2.0		


VACUUM GAUGE
MERCURY COLUMN
GAUGE : INCHES
0
2
4
6
8
10
12
14
16
18
20

MECHANICAL ENGINEERING LABORATORY

ARMOUR INSTITUTE OF TECHNOLOGY

Date Thurs., Apr. 8, 1915.

CALIBRATION OF PRESSURE GAUGE.

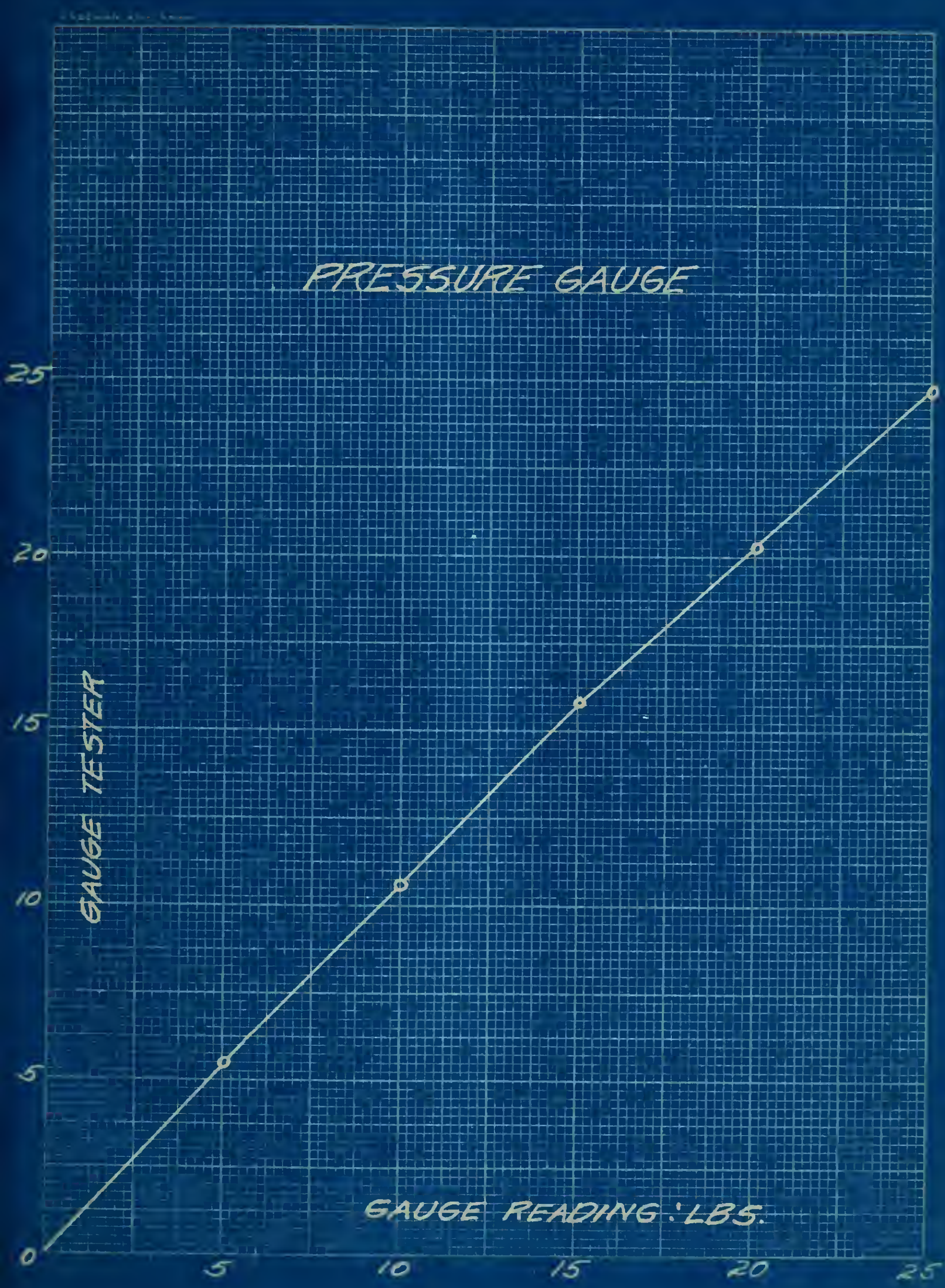
By comparison with Square Inch Gauge Tester.

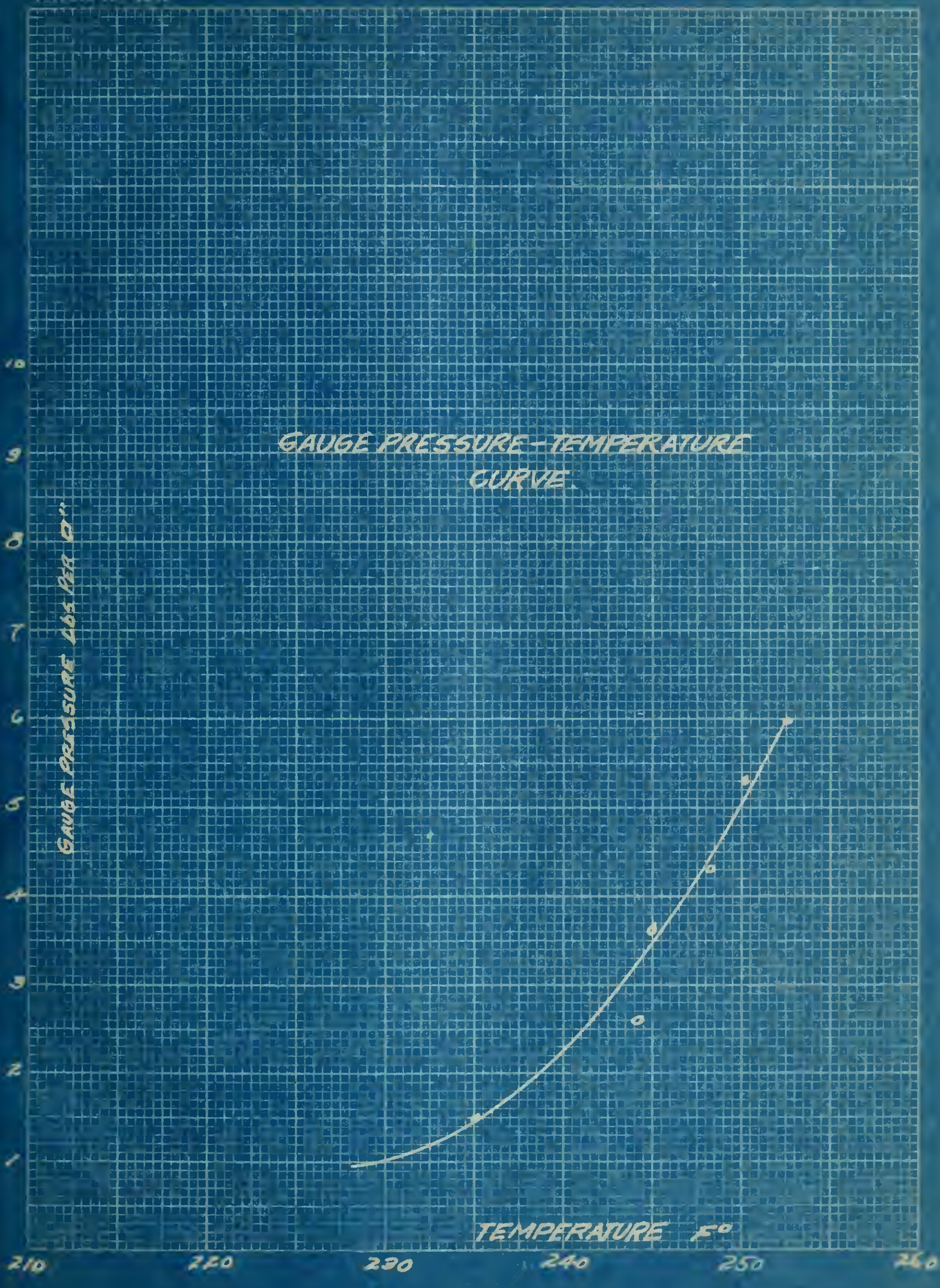
Maker and number of gauge Ashcroft Mfg. Co.

Observer I. Yamamoto, C. Diemecke.

NUMBER	READING GAUGE TESTER POUNDS	GAUGE READING IN POUNDS						ERROR %	
		BEFORE ADJUSTMENT			AFTER ADJUSTMENT			BEFORE ADJUSTMENT	AFTER ADJUSTMENT
		UP	DOWN	MEAN	UP	DOWN	MEAN		
	5	5.2	5.3	5.25					
	10	10.2	10.3	10.25					
	15	15.3	15.4	15.35					
	20	20.0	20.2	20.1					
	25	24.8	24.9	24.85					
	30	29.7	29.7	29.7					

A curve was plotted and the correct readings were taken from this.


PRESSURE GAUGE
GAUGE TESTER
GAUGE READING: LBS.
0
5
10
15
20
25
5
10
15
20
25

GAUGE PRESSURE-TEMPERATURE
CURVE
GAUGE PRESSURE LBS PER □"
TEMPERATURE F°
10
9
8
7
6
5
4
3
2
1
210
220
230
240
250
260

Formulae.

Heat lost by steam.

(1) $H_1 = W(xr_1 \pm t_1 - t_2)$.

H_1 = heat lost by steam.
W = weight of condensed steam.
x = quality of steam.
r_1 = latent heat of steam.
t_1 = temperature of steam at inlet.
t_2 = temperature of steam at exhaust.

Heat transferred to water.

(2) $H_2 = W(t_3 - t_4) \pm wr_2$.

H_2 = heat transferred to water.
W = total water added.
w = total water vaporized,
r_2 = latent heat of vaporization of water.
t_3 = boiling point of water at that vacuum.
t_4 = temperature of water at inlet.

Rate of Evaporation.

(3) $R = \frac{w}{S(H_1 - t_3)}$.

R = rate of evaporation in lbs. per sq. ft. per B. T. U.

(3)

S = total heating surface, sq. ft.

H_3 = heat used to raise water to boiling point.

Capacity of evaporator.

(4) $$C = 7.48 \frac{\left(w \pm \frac{H_3}{r_2}\right)}{SdT}.$$

C = capacity of evaporation in gallons per sq. ft. per hour.

d = density of water in lbs. per cu. ft.

T = time in hours.

These formulae were taken from Gebhard's "Steam-Power Plant Engineering". The values of The latent heats of vaporization of water were taken from Kent's "Pocket Book for Mechanical Engineers", from which the densities of water at various temperatures were also taken.

Data and Calculations of Runs.

Run I.

Charged		Withdrawn	
Weight	Temperature	Weight	Temperature
180.5 lbs.	58' F.	147.5 lbs.	Boiling point.
181.0	52	24.5	" "
97.5	88		
67.0	53		
47.0	60		
45.0	54		
30.0	54		
20.0	54		
25.5	54		
16.5	54		
710.0 lbs.		172.0 lbs.	

Total water charged,	710.0 lbs.
Total water withdrawn,	172.0 "
Total water evaporated,	538.0 "

Run I.

Time	Pressure	Vacuum	Steam Temperature Inlet	Steam Temperature Exhaust	Condensed Steam-Wt.
2:58	6.6#	19.6"	252' F.	170' F.	
3:03	5.7	19.2	255	170	
:08	6.5	18.8	253	174	
:13	4.3	18.8	252	174	
:18	5.0	18.8	250	174	152 lbs.
:23	6.5	18.8	250	176	
:28	7.0	18.8	251	175	
:33	4.0	17.0	248	173	159
:38	4.0	16.8	246	172	
:43	4.0	16.8	245	171	
:48	3.7	20.0	245	168	105
:53	6.0	20.0	251	168	
:58	5.5	19.0	250	163	175
Avge.	5.3#	18.7"	250'F.	171' F.	591 lbs.

Run 1.

Calculations.

Absolute pressure,	20.5 lbs.
Quality of steam,	95%
Heat of vaporization at 20.5,	959.15 BTU
Temperature of steam at inlet,	250' F.
Temperature of steam at exhaust,	171' F.
Steam consumption.	671 lbs.
Heat lost by steam,	
671(.95 x 959.15 + 250 - 171) =	665000 BTU.
Average vacuum,	18.9 in.
Absolute pressure,	5.4 lbs.
Boiling point of water at 5.4,	165.8' F.
Density of water, I cu. ft..	60.85 lbs.
Heat of vaporization at 5.4.	998.0
Total water charged,	710 lbs.
Total water withdrawn,	172 "
Total water evaporated,	538 "
Heat used to raise water to boiling point,	
180.5# at 58, 180.5 x 107.8,	19450 B.T.U.
181 at 52, 181 x 113.8,	19650
97.5 at 88, 97.5 x 77.8,	7580
97 at 53, 97 x 112.8,	10950
47 at 60, 47 x 105.8,	4970
107 at 54, 107 x 111.8,	11950

Run 1.

Heat used to vaporize, 538 lbs.,

538 x 998.0, 537000 B.T.U.

Total heat transferred, 611530 B.T.U.

Efficiency, 92%

Rate of evaporation,

$$R = \frac{538}{52(665000 - 75430)} = 0.00001756 \text{ lbs. per sq.ft. per B.T.U.}$$

Run 2.

Charged		Withdrawn.	
Weight	Temperature.	Weight	Temperature
185 lbs.	53' F.	23.0 lbs.	Boiling Point.
185	53	90.0	" "
188	52	24.0	" "
130	52	47.5	" "
688 lbs.		184.5 lbs.	

Total water charged,	688.0 lbs.
Total water withdrawn,	184.5 "
Total water evaporated,	503.5 "

Run 2.

Time	Pressure	Vacuum	Steam Temperature Inlet	Exhaust	Condensed Steam-Wt.
1:17	5.5#	14.4"	251' F.	156' F.	
:22	4.0	20.0	245	178	
:27	5.7	19.6	250	190	
:32	5.4	19.6	250	188	
:37	7.4	19.6	252	184	197 lbs.
:42	6.5	20.4	252	178	
:47	4.3	19.8	249	184	
:52	5.2	19.8	250	185	
:57	4.0	19.0	249	186	217
2:02	5.0	19.8	250	184	
:07	3.0	20.5	245	182	
:12	5.8	19.6	245	176	
:17	3.0	20.0	244	180	235
Avge.	4.97#	19.4"	250' F.	181' F.	649 lbs.

Run 2.

Calculations.

Absolute pressure of steam,	19.8 lbs.
Quality of steam,	95%
Heat of vaporization at 19.8,	960.4 B.T.U.
Temperature of steam at inlet,	250' F.
Temperature of steam at exhaust,	131' F.
Steam consumption,	637.5 lbs.
Heat lost by steam,	
637.5(.95 x 960.4 ± 250 - 131) =	625500 B.TU.
Average vacuum,	19.4 in.
Absolute pressure,	5.05 lbs.
Boiling point of water at 5.05,	162.7' F.
Heat of vaporization at 5.05,,	1000 B.T.U.
Density of water, 1 cu. ft.,	60.93 lbs.
Total water charged,	/ 688.0 lbs.
Total water withdrawn,	184.5 "
Total water evaporated,	503.5 "
Heat used to raise water to boiling point,	
370 lbs at 53', 370 x 109.7,	40530 B.T.U.
318 " at 52', 313 x 110.7,	35200
Heat used to vaporize 503.5 lbs.,	
503.5 x 1000 --	503500
Total heat transferred,	579230 B.T.U.

Run 2.

Efficiency, 92.5%

Rate of evaporation,

$$R = \frac{503.5}{52(625500 - 75730)} = 0.00001766 \text{ lbs. per sq. ft. per B.T.U.}$$

Capacity of evaporator,

$$C = \frac{7.48(503.5 \pm \overset{75730}{1000}))}{52 \times 60.95 \times 1} = 1.56 \text{ gallons per sq. ft. per hour.}$$

Run 3.

Charged		Withdrawn	
Weight	Temperature	Weight	Temperature
163.0 lbs.	162' F.	146.0 lbs.	Boiling point.
168	161	57.5	" "
153.	151		
126.5	161		
101.	158		
82.	158		
793.5 lbs.		203.5 lbs.	

Total water charged,	793.5 lbs.
Total water withdrawn,	203.5 "
Total water evaporated,	590.0 "

Run 3.

Time	Pressure	Vacuum	Steam Temperature Inlet	Steam Temperature Exhaust	Condensed Steam-Wt.
2:50	4.5#	19.8"	247' F.	153' F.	
:55	4.7	19.4	247	186	
3:00	5.6	19.4	247	186	
:05	4.6	19.4	247	186	153. lbs.
:10	5.1	18.4	248	190	
:15	7.2	19.6	250	184	
:20	6.4	19.6	254	179	126.5
:25	7.5	18.4	253	182	
;30	7.5	19.0	253	178	151.
:35	7.8	19.0	253	179	
:40	4.3	19.0	255	168	127.
/ :45	4.6	19.4	250	174	
:50	4.6	19.6	249	174	82.
Avge.	5.5#	19.3"	252' F.	179.5' F.	639.5 lbs.

Run 3.

Calculations.

Absolute pressure of steam,	20.68 lbs.
Quality of steam	95%
Heat of vaporization at 20.68,	958.9 B.T.U.
Temperature of steam at inlet,	252' F.
Temperature of steam at exhaust,	179.5' F.
Steam consumption,	639.5 lbs.
Heat lost by steam,	
639.5(.95 x 958.9 + 252 - 179.5) =	628500 B.T.U.
Average vacuum,	19.03 in.
Absolute pressure,	5.23 lbs.
Boiling point of water at 5.23,	164.2' F.
Heat of vaporization at 5.23,	999.3 B.T.U/
Density of water, 1 cu. ft.,	60.90lbs.
Total water charged,	793.5 lbs.
Total water withdrawn,	203.5 "
Total water evaporated,	590.0 "
Heat used to raise water to boiling point,	
163# at 162', 163 x 2.4,	392 B.T.U.
294.5 at 161, 294.5 x 3.2,	941
153 at 158, 153 x 13.2,	2020
183 at 158, 183 x 6.2,	1134

Run 5.

Heat used to vaporize 590 lbs.,

590 x 999.3, 588500 B.T.U.

Total heat transferred, 592987 B.T.U.

Efficiency, 94.5%

Rate of evaporation,

$$R = \frac{590}{52(628500 - 4487)} = 0.00001828 \text{ lbs. per sq. ft. per B.T.U.}$$

Capacity of evaporation,

$$C = \frac{7.48(590 \pm \overset{4487}{\overline{999.3}})}{52 \times 60.90 \times 1} = 1.41 \text{ gallons per sq. ft. per hour.}$$

Run 4.

Charged		Withdrawn.	
Weight	Temperature	Weight	Temperature.
146. lbs.	164' F/	61. lbs.	Boiling point.
139.5	158	175.	" "
128.5	166	13.5	" "
124.5	173		
538.5 lbs.		249.5 lbs.	

Total water charged,	538.5 lbs.
Total water withdrawn,	249.5 "
Total water evaporated,	289.0 "

Run 4.

Time	Pressure	Vacuum	Steam Temperature Inlet	Steam Temperature Exhaust	Condensed Steam-Wt.
4:10	7.o#	16.0"	253' F.	163' F.	
:15	6.6	17.4	254	188	
:20	8.3	15.2	255	186	128.5 lbs.
:25	7.0	14.0	253	186	
:30	6.7	15.6	254	191	
:35	5.5	14.8	252	192	124.5
:40	6.0	14.4	250	193	68.5
Avge.	6.7#	15.3"	253' F.	185' F.	321.5 lbs.

Run 4.

Calculations.

Absolute pressure of steam,	21.58 lbs.
Quality of steam,	95%
Heat of xaporization at 21.58,	957.3 B.T.U.
Temperature of steam at inlet,	255' F.
Temperature of steam at exhaust,	185' F.
Steam consumption,	321.5 lbs.
Heat lost by steam,	
321.5(.95 x 957.3 ± 255 - 185) =	314400 B.T.U.
Average vacuum,	15.[illegible] in.
Absolute pressure,	7.06 lbs.
Boiling point of water at 7.06,	177.2' F.
Heat of vaporization at 7.06,	991.6 B.T.U.
Density of water, 1 cu. ft.,	60.63 lbs.
Total water charged,	538.5 lbs.
Total water withdrawn,	249.5 "
Total water evaporated,	289.0 "
Heat used to raise water to boiling point,	
146# at 164', 146 x 13.2,	1952 B.T.U.
139.5 at 158, 139.5 x 19.2,	2680
128.5 at 166, 128.5 x 11.2,	1440
124.5 at 176, 124.5 x 1.2,	149

Run 4.

Heat used to vaporize 289 lbs.,

289 x 991.6, 286000 B.T.U.

Total heat transferred, 292194 B.T.U.

Efficiency, 93%

Rate of evaporation,

$$R = \frac{289}{52(314400 - 6194)} = 0.00001804 \text{ lbs. per sq. ft. per B.T.U.}$$

Capacity of evaporation,

$$C = \frac{7.48(289 + \frac{6194}{991.6})}{52 \times 60.65 \times 0.5} = 1.40 \text{ gallons per sq. ft. per hour}$$

Run 5.

Charged Weight	Charged Temperature	Withdrawn Weight	Withdrawn Temperature
163.5 lbs.	67' F.	84 lbs.	Boiling point
147.	67		
310.5 lbs.		84 lbs.	

Total water charged,	310.5 lbs.
Total water withdrawn,	84.0 "
Total water evaporated,	226.5 "

Time	Pressure	Vacuum	Steam Temperature Inlet	Steam Temperature Exhaust	Condensed Steam-Wt.
9:05	8.5#	20.4"	255' F.	154' F.	
:10	8.0	17.8	254	178	
:15	5.4	19.0	255	185	
:20	6.0	18.8	253	185	
:25	4.3	18.8	252	186	167.5 lbs.
:30	8.6	18.6	253	199	
:35	9.4	19.0	253	200	122.5
Avge.	7.3#	18.9"	253' F.	185' F.	290.0 lbs.

Run 5.

Calculations.

Absolute pressure of steam,	22.35 lbs.
Quality of steam,	95%
Heat of vaporization at 22.35,	956.1 B.T.U.
Temperature of steam at inlet,	253' F.
Temperature of steam at exhaust,	185.3' F.
Steam consumption,	290 lbs.
Heat lost by steam,	
290(.95 x 956.1 + 253 - 185.3) =	283400 B.T.U.
Average vacuum,	18.9 in.
Absolute pressure,	5.3 lbs.
Boiling point at 5.3,	164.5' F.
Heat of vaporization at 5.3,	999.0 B.T.U.
Density of water, 1 cu. ft.,	60.89 lbs.
Total water charged,	310.5 lbs.
Total water withdrawn,	84 "
Total water evaporated,	226.5 "
Heat used to raise water to boiling point,	
310.5# at 67', 310.5 x 97.6,	30300 B.T.U.
Heat used to vaporize 226.5 lbs.,	
226.5 x 999,	226500
Total heat transferred,	256800 B.T.U.

Run 5.

Efficiency, 90.7%

Rate of evaporation,

$$R = \frac{226.5}{52(283400 - 30300)} = 0.00001712 \text{ lbs. per sq. ft. per B.T.U.}$$

Capacity of evaporator,

$$C = \frac{7.48\left(226.5 + \frac{30300}{999}\right)}{52 \times 60.89 \times 0.5} = 1.21 \text{ gallons per sq. ft. per hour.}$$

Run 6.

Charged		Withdrawn	
Weight	Temperature	Weight	Temperature
182 lbs.	54' F.	99.5 lbs.	Boiling point
178	53		
360 lbs.			

Total water charged,	360. lbs.
Total water withdrawn,	99.5 "
Total water evaporated,	260.5 "

			Steam Temperature		Condensed
Time	Pressure	Vacuum	Inlet	Exhaust	Steam-Wt.
10:20	4.03	19.8"	248' F.	154' F.	
:25	5.7	20.4	252	178	
:30	3.4	19.4	250	195	
:35	4.0	19.2	250	188	169.5 lbs.
:40	5.0	19.4	250	190	
:45	6.7	19.4	251	195	
:50	6.0	19.4	250	202	161.
Avge.	5.0#	19.57"	250' F.	186' F.	330.5 lbs.

Run 6.

Calculations.

Absolute pressure of steam,	19.8 lbs.
Quality of steam,	95%
Heat of vaporization at 19.8,	960.4 B.TU.
Temeprature of steam at inlet,	250' F.
Temperature of steam at exhaust,	186' F.
Steam consumption,	330.5 lbs.
Heat lost by steam,	
330.5(.95 x 960.4 + 250 - 186) =	322500 B.T.U.
Average vacuum,	19.57 in.
Absolute pressure,	4.98 lbs.
Boiling poimt of water at 4.98,	162.1' F.
Heat of vaporization at 4.98,	995.9 B.TU.
Density of water, 1 cu. ft.,	60.94 lbs.
Total water charged,	360. lbs.
Total water withdrawn,	99.5 "
Total water evaporated,	260.5 "
Heat used to raise water to boiling point,	
182# at 54', 182 x 108.1,	19700 B.T.U.
178# at 53', 178 x 109.1,	19420
Heat used to vaporize 260.5 lbs.,	
260.5 x 995.9,	259500
Total heat transferred,	298620 B.T.U.

Run 6.

Efficiency, 92.5%

Rate of evaporation,

$$R = \frac{260.5}{52(322500 - 39120)} = 0.00001770 \text{ lbs. per sq. ft. per B.T.U.}$$

Capacity of evaporator,

$$C = \frac{7.48\left(260.5 \pm \frac{39120}{995.9}\right)}{52 \times 60.94 \times 0.5} = 1.42 \text{ gallons per sq. ft. per hour.}$$

Run 7.

Charged		Withdrawn	
Weight	Temperature	Weight	Temperature
168. lbs.	111' F.	175.5 lbs.	Boiling point
163.5	111	28.5	" "
		204.0 lbs.	
144	153		
129.5	159		
126	150		
47.5	150		
778.5 lbs.			

Total water charged,	778.5 lbs.
Total water withdrawn,	204.0 "
Total water evaporated,	574.5 "

Run 7.

Time	Pressure	Vacuum	Steam Temperature Inlet	Steam Temperature Exhaust	Condensed Steam-Wt.
11:24	2.6#	19.4"	248' F.	179' F.	
:29	5.0	19.8	250	193	
:34	6.7	19.4	252	194	
:39	6.8	18.0	253	189	144. lbs.
:44	6.2	19.2	252	199	
:49	6.9	16.2	253	205	
:54	7.0	19.6	253	193	129.5
:59	7.1	19.4	253	190	
12:04	7.7	19.6	253	183	
:09	7.0	19.6	253	180	126.
:14	6.8	18.0	252	190	
:19	7.8	19.9	252	186	130
:24	6.0	18.8	252	187	127.
Avge.	6.4#	19.0"	252' F.	190' F.	656.5 lbs.

Run 7.

Calculations.

Absolute pressure of steam,	21.10 lbs.
Qualiyt of steam,	95%
Heat of vaporization at 21.10,	958.1 B.T.U.
Temperature of steam at inlet,	252' F.
Temperature of steam at exhaust,	190' F.
Steam consumption,	656.5 lbs.
Heat lost by steam,	
656.5(.95 x 958.1 + 252 - 190) =	638200 B.T.U.
Average vacuum,	18.98 in.
Absolute pressure,	5.35 lbs.
Boiling point of water at 5.35,	165' F.
Heat of vaporization at 5.35,	998.7 B.T.U.
Density of water, 1 cu. ft.,	60.97 lbs.
Water charged, total,	778.5 lbs.
Total water withdrawn,	204. "
Total water evaporated,	574.5 "
Heat used to raise water to boiling point,	
331.5# at 111', 331.5 x 54,	17900 B.T.U.
144 at 159, 144 x 12,	1728
129.5 at 159, 129.5 x 6,	768
173.5 at 150, 173.5 x 15,	2600
Heat used to vaporize 574.5 lbs.,	
574.5 x 998.7,	573000

T

Run 7.

otal heat transferred, 595990 B.T.U.

Efficiency, 93.4%

Rate of evaporation,

$$R = \frac{574.5}{52(638200 - 22996)} = 0.00001795 \text{ lbs. per sq. ft. per B.T.U.}$$

Capacity of evaporator,

$$C = \frac{7.48\left(574.5 + \frac{22996}{998.7}\right)}{52 \times 60.87 \times 1} = 1.41 \text{ gallons per sq. ft. per hour.}$$

Run [illegible].

Charged		Withdrawn	
Weight	Temperature	Weight	Temperature
175.5 lbs.	63' F.	156.5 lbs.	Boiling point
128.5	62	57.	" "
143.5	167	213.5 lbs.	
112.5	170		
124.5	173		
684.5 lbs.			

Total water charged,	684.5 lbs.
Total water wuthdrawn,	213.5 "
Total water evaporated,	471.0 "

Run 8.

Time	Pressure	Vacuum	Steam Temperature Inlet	Steam Temperature Exhaust	Condensed Steam-Wt.
10:11	5.8#	15.[illegible]"	245' F.	142' F.	
:16	5.0	12.0	246	195	
:21	5.8	15.4	250	203	
:26	6.4	16.8	252	199	143.5 lbs.
:31	5.5	11.8	252	191	
:36	4.7	18.2	251	188	
:41	4.0	18.6	251	185	166.5
:46	4.8	18.6	251	185	
:51	3.2	18.0	250	185	
:56	4.4	18.4	250	191	124.5
11;01	6.4	18.2	251	191	
:06	6.9	18.[illegible]	251	187	
:11	7.6	18.6	251	183	115.5
Avge.	5.42#	16.03"	250' F.	186.6' F.	550.0 lbs.

Run 8.

Calculations.

Absolute pressure of steam,	20.3 lbs.
Quality of steam,	95%
Heat of vaporization at 20.3,	959.9 B.T.U.
Temperature of steam at inlet,	250' F.
Temperature of steam at exhaust,	186.6' F.
Steam consumption,	550 lbs.
Heta olst by steam,	
550(.95 x 959.5 ± 250 - 186.6) =	535500 B.T.U.
Average vacuum,	16.03 in.
Absolute pressure,	6.56 lbs.
Boiling point of water at 6.56,	174.4' F.
Heat of vaporization at 6.56,	993.6 B.T.U.
Density of water, 1 cu. ft.,	60.67 lbs.
Total water charged,	684.5 lbs.
Total water withdrawn	213.5 "
Total water evaporated,	471.0 "
Heat used to raise water to boiling point,	
175.5# at 63', 175.5 x 111.4,	19580 B.T.U.
128.5 at 62, 128.5 x 112.4.	14450
143.5 at 167, 143.5 x 7.4,	1046
112.5 at 170, 112.5 x 4.4,	495
124.5 at 173, 124.5 x 1.4,	160

Run 8.

Heat to vaporixe 471 lbs.,

471 x 993.6,	468500 B.T.U.
Total heat transferred,	504231 B.T.U.
Efficiency,	94.2%

Rate of evaporation,

$$R = \frac{471}{52(335500 - 35731)} = 0.00001811 \text{ lbs. per sq. ft. per B.T.U.}$$

Capacity of evaporator,

$$C = \frac{7.48\left(471 + \frac{35731}{993.5}\right)}{52 \times 60.67 \times 1} = 1.21 \text{ gallons per sq. ft. per hour}$$

Run 9.

Charged		Withdrawn	
Weight	Temperature	Weight	Temperature
168.25 lbs.	68' F.	157. lbs.	Boiling point
172.25	56	57.25 "	" "
130.25	58	214.25 lbs.	
131.75	57		
602.50 lbs.			

Total water charged,	602.50 lbs.
Total water withdrawn,	214.25 "
Total water evaporated,	388.25 "

Run 9.

Time	Pressure	Vacuum	Steam Temperature Inlet	Exhaust	Condensed Steam-Wt.
1:40				107' F.	
:45	2.6#	16.0"	251' F.	160	
:50	4.3	17.6	248	168	
:55	4.5	17.0	249	158	
2:00	3.3	17.6	250	169	130. lbs.
:05	4.8	17.6	248	17[illegible]	
:10	3.5	15.6	249.5	166	
:15	3.2	17.6	248	167	110.5
:20	2.6	17.6	247.5	172	61.75
:25	3.6	16.2	245	164	
:30	2.6	17.8	244	16[illegible]	
:35	4.[illegible]	18.0	244	168	
:40	1.5	17.8	244	168	132.25
Avge.	3.32#	17.23"	247.9'F.	16[illegible]'F.	434.5 lbs.

Run 9.

Calculations.

Absolute pressure of steam,	18.11 lbs.
Quality of steam,	95%
Heat of vaporization at 18.11,	963.5 B.T.U.
Temperature of steam at inletm	247.9' F.
Temperature of steam at exhaust,	162' F.
Steam consumption,	484.5 lbs.
Heat lost by steam,	
484.5(.95 x 963.5 + 247.9 - 162) =	488800 B.T.U.
Average vacuum,	17.25 in.
Absolute pressure,	5.98 lbs.
Boiling point of water at 5.98,	169.9' F.
Heat of vaporization at 5.98,	995.9 B.T.U.
Density of water, 1 cu. ft.,	60.77 lbs.
Total water charged,	602.50 lbs.
Total water withdrawn,	214.25 "
Total water evaporated,	388.25 "
Heat used to raise water to boiling point,	
168.25# at 68', 168.25 x 101.9,	17150 B.T.U.
172.25 at 56, 172.25 x 113.9,	19600
130.25 at 58, 130.25 x 111.9,	14800
131.75 at 57, 131.75 x 112.9,	14850

Run 9.

Heat used to vaporize 388.25 lbs.,

38825 x 995.9,	386500 B.T.U.
Total heat transferred,	452880 B.T.U.
Efficiency,	92.8%

Rate of evaporation,

$$R = \frac{388.25}{52(458800 - 36380)} = 0.0000177l \text{ lbs. per sq. ft. per B.T.U.}$$

Capacity of evaporator,

$$C = \frac{7.48(388.25 + \frac{36380}{995.9})}{52 \times 60.77 \times 1} = 1.08 \text{ gallons per sq. ft. per hour.}$$

Run 10.

Charged		Withdrawn	
Weight	Temperature	Weight	Temperature
161.5 lbs.	57' F.	165 lbs.	Boiling point
147.	57	59	" "
144.	56		
148.25	57		
600.75 lbs.		224 lbs.	

Total water charged,	600.75 lbs.
Total water withdrawn,	224. "
Total water evaporated,	376.75 "

Run 10.

Time	Pressure	Vacuum	Steam Temperature Inlet	Steam Temperature Exhaust	Condensed Steam-Wt.
3:08				116' F.	
;13	2.0#	12.8"	246' F.	162	
:18	2.8	15.0	246	175	95. lbs.
:23	2.4	17.4	247.5	173	
:28	2.5	18.0	249	174	103.5
:33	1.9	18.0	247.5	174	
:38	3.6	15.6	248	172	
:43	3.0	17.8	246	173	113.75
:48	3.0	17.8	246	172	
:53	3.0	17.8	248	171	
:58	3.7	15.6	250	170	97.75
4:03	2.5	18.0	247.5	166	
:08	1.6	18.0	247	172	63.
Avge.	2.67#	16.9"	248' F.	167' F.	473. lbs.

Run 10.

Calculations.

Absolute pressure of steam,	17.31 lbs.
Quality of steam,	95%
Heat of vaporization at 17.31,	965 B.T.U.
Temperature of steam at inlet,	248' F.
Temperature of steam at exhaust,	167' F.
Stam consumption,	473 lbs.
Heat lost by steam,	
473(.95 x 965 ± 248 - 167) =	472000 B.T.U.
Average vacuum,	16.9 in.
Absolute pressure,	6.15 lbs.
Boiling point of water at 6.15,	171.24' F.
Heat of vaporization at 6.15,	995.2 B.T.U.
Density of water, 1 cu. ft.,	60.75 lbs.
Total water charged,	600.75 lbs.
Total water withdrawn,	224. "
Total water evaporated,	376.75 "
Heat used to raise water to boiling point,	
456.75 at 57', 456.75 x 114.24,	52190 B.TU.
144 at 56, 144 x 115.24,	16600
Heat used to vaporize 376.75 lbs.,	
376.75 x 995.2,	375000

Run 10.

Total heat transferred, 443790 B.T.U.

Efficiency, 94.2%

Rate of evaporation,

$$R = \frac{376.75}{52(472000 - 68790)} = 0.00001798 \text{ lbs. per sq. ft. per B.T.U.}$$

Capacity of evaporator,

$$C = \frac{7.48(376.75 + \frac{68790}{995.2})}{52 \times 60.75 \times 1} = 1.05 \text{ gallons per sq. ft. per hour.}$$

Summary of Results.

When the liquid is in level with the top tubes.	Rate of evaporation in lbs. per sq. ft. per B.T.U.	Capacity of evaporator in gallons per sq. ft. per hour.	Efficiency.
Run 1.	1.756 x 10^{-5}	1.44	92.0%
Run 2.	1.766 x "	1.36	92.5
Run 3.	1.828 x "	1.41	94.5
Run 4.	1.804 x "	1.40	93.0
Run 7.	1.795 x "	1.41	93.4
Run 8.	1.811 x "	1.21	94.2
Run 9.	1.770 x "	1.08	92.8
Run 10.	1.793 x "	1.06	94.2
Average.	1.790 x 10^{-5}	1.30	93.32%
When the liquid was boiled down.			
Run 5.	1.712 x 10^{-5}	1.21	90.7%
Run 6.	1.741 x "	1.42	92.5
Average.	1.727 x 10^{-5}	1.31	91.6%

Part 4.

Conclusion.

Comparison of Results.

Comparison of Results.

From the results that we have obtained, it is evident that the new "Swenson-Kerner" type of evaporator is exceedingly efficient. The new double-tube type has an average efficiency of 93.32% when the liquid in the evaporator is kept at the upper level of the top tubes, whereas the old single-tube type has, according to previous workers, an average efficiency of 87.0% when tested under the same conditions. The new type has an average capacity of evaporation of I.3 gallons per sq. ft. per hour, whereas the old type has an average capacity of only 0.615 gallons per sq. ft. per hour.The rate of evaporation of the new type, however, is lower than that of the old type, being but 0.00001790 lbs. per sq. ft. per B.T.U. as compared to 0.00007280 lbs. per sq. ft. per B.T.U. for the old type. The comparison between the two types is shown in the following table:

	Rate of evap. per sq. ft. per B.T.U.	Cap. of evap. in gallons per sq. ft. per hour.	Efficiency.
New double-tube type.	0.00001790#	1.30	93.32%
Old single-tube type.	0.00007280	0.615	87.00
Difference.	0.00003490#	0.685	6.32%

When the liquid was boiled down, both the rate of evaporation and the efficiency were lower than when the liquid was kept constant level with the upper side of the top tubes; but the capacity of evaporation was the same in either case. The following table makes the distinction clear:

Condition of liquid.	Rate of evap. in lbs. per sq. ft. per B.T.U.	Cap. of evap. gallons per sq. ft. per hour.	Efficiency.
Constant level.	0.00001790	1.30	93.32%
Boiled down.	0.00001741	1.31	91.60
Difference.	0.00000049	0.01	1.72%

Discussion.

Discussion.

This type of evaporator was invented by Mr. Martin L. Kermer of the Swenson Evaporator Company. A patent was granted but the evaporator was not put on the market because the inventor was working on the improvement of certain features which had caused difficulty in operation. The evaporator we worked on is one of the first built by the company and has been improved on in the later models.

We have watched the evaporator closely during all our work, and from these observations and from our results, we have arrived at certain conclusions which Mr. Kermer had assumed in his theory for the design of this type. If future workers will follow these conclusions, they will avoid many of the difficulties which we encountered in our work, and their results will be much better than those we have obtained. However, there are several improvements which

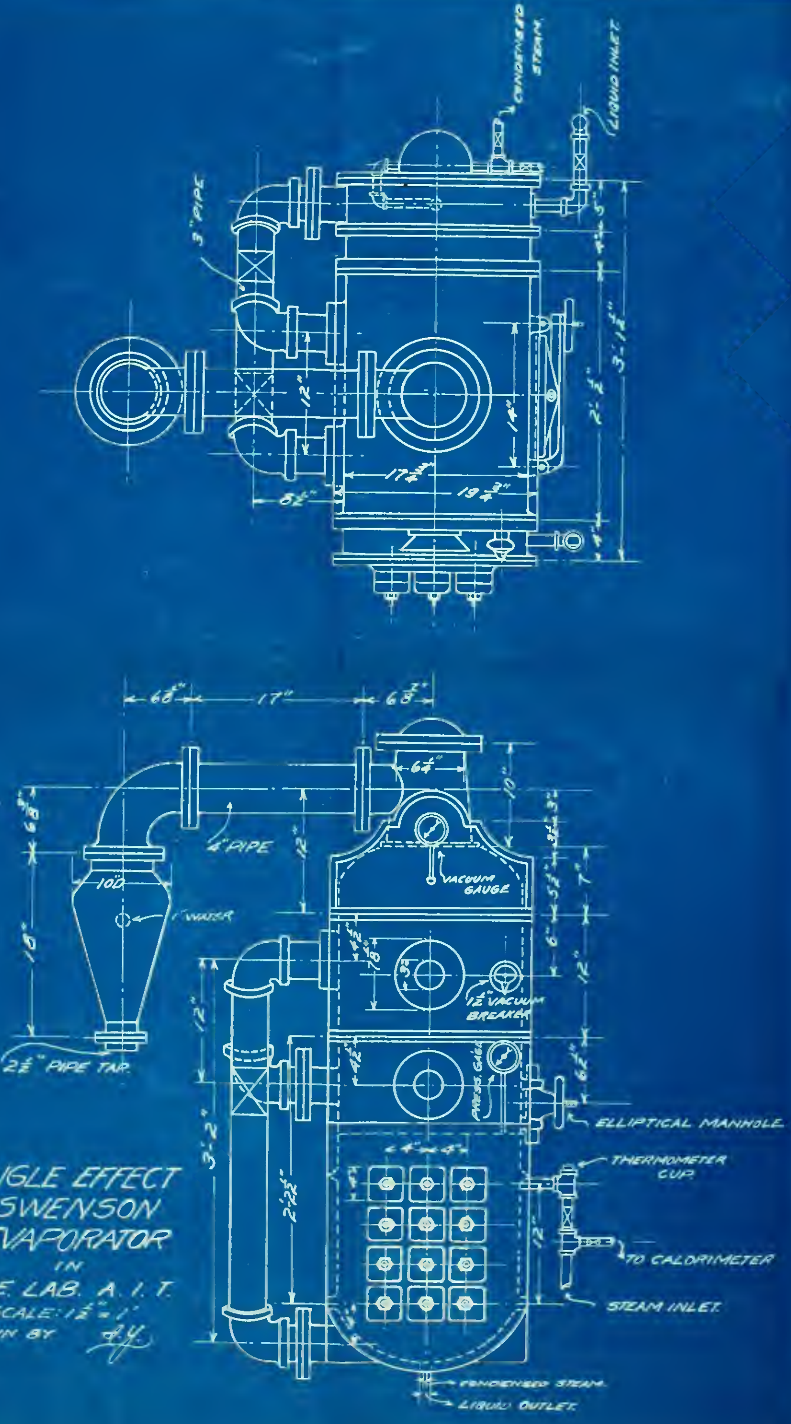
must be made on this evaporator before such results can be realized.

Our work has led us to the following conclusions as regards the most efficient operation of the evaporator; The liquid to be evaporated must be fed continuously into the evaporator, and at the same time, the drains for condensed steam must be left wide open, even if some of the exhaust steam escapes without condensing. This tends to keep the steam pressure down to barometric pressure, and reduces the vacuum down to about 14 inches, making a difference of but 30' F. between the temperature of steam and the boiling point. It prevents the throttling of the steam in the steam pipes and allows it to pass through at its maximum velocity, thus tending to keep the efficiency constant but increasing the capacity several times. The velocity of the vapors in the inner tubes is enormous, being over 10,000 feet per second, so that the liquid in the tubes is evaporated in a few seconds. The

evaporator as it is set up at present, provides no connection between the inner tubes and the body of the evaporator other than that of the liquor pipe leading from the liquor chests to the inner tubes and to the body. If an interconnecting pipe were put in so as to connect the body of the evaporator at its lowest point with the inner tubes, these would be filled up as quickly as the liquid in them is evaporated. The machine has no such connection, and when both pipe valves are open, and the water is charged only intermittently, the inner tubes are practically empty all the time, thus throwing out 40% of the heating surface during practically all the run. If this interconnection were provided, and the conditions of running as previously advised were followed, the capacity of the evaporator would rise to about 4.5 gallons per sq. ft. per hour, and the inventor hopes to increase this to even 5 gallons. The efficiency of the machine would also increase,

and it must be kept in mind that all these values would be obtained at a temperature difference between steam and boiling point of the water of only 30' F. instead of a difference of 85' F. as obtained in our work. We made some observations as nearly as possible under these conditions, charging continuously, but lacking the inter-connection, and the results led us to verify Mr. Kermer's theory.

With such a connection and under those running conditions, the evaporator would be one of the most efficient built, and would have an unusually large capacity for its size.



SINGLE EFFECT
SWENSON
EVAPORATOR
IN
Ch. E. LAB. A. I. T.
SCALE: 1½" = 1'
DRAWN BY A.Y.